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Extreme High and Low Temperature Operation of the Silicon-On-Insulator Type CHT-OPA Operational Amplifier

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Scope of Work

Integrated circuit chips that are manufactured using silicon-on-insulator (SOI) technology provide faster switching, consume less power, and offer better radiation-tolerance compared to their conventional silicon counterparts. They also exhibit reduced leakage current and, thus, they are often tailored for high temperature operation. These attributes make SOI-based devices suitable for use in harsh environments where extreme temperatures and wide thermal swings are anticipated. Such applications include planetary surface exploration, deep space probes, jet engine compartment, all-electric boat, oil and gas well logging, and satellite systems, to name a few. Electronics designed for such applications are desired to function reliably without the need for any thermal management. The elimination of thermal control allows saving in electronic system mass, simplifies its design, and improves its reliability. A new operational amplifier based on silicon-on-insulator technology was recently introduced by CISSOID Company in Belgium. The CHT-OPA chip is a low power, precision amplifier with supply voltage operation between 4.5 and 20 volts [1]. It is rated for operation from -55 °C to +225 °C with a 15 mA output current capability. The quad amplifier chip is designed as a 14-pin, hermetically-sealed device in a ceramic package. Table I shows some of the device manufacturer's specifications.

Table I. Specifications of the evaluated CHT-OPA operational amplifier [1].

Parameter (Unit)	**Value**
Supply Voltage (V)	4.5 to 20
Supply Current (mA)	0.3 to 0.6
Output Current (mA)	15
Bandwidth (MHz)	1.3
Slew Rate (V/µs)	1.5
Temperature Range (°C)	-55 to +225
Package	DIL-14 ceramic
Lot #	548

An amplifier circuit configured in a unity gain, inverting configuration was constructed utilizing the CHT-OPA chip and a few passive components. The circuit was evaluated in the temperature range between -190 °C and +200 °C in terms of signal gain, phase shift, and supply current. These properties were recorded at selected test temperatures in the frequency range of 1 kHz to 5 MHz. At each test temperature, the device was allowed to soak for 15 minutes before any measurements were made. Extreme-temperature re-start capability, i.e. power switched on while the device was at extreme temperatures, was also investigated. In addition, the effects of thermal cycling under a wide temperature range on the operation were determined. The circuit was exposed to a total of 10 cycles between -190 °C and +200 °C at a temperature rate of 10 °C/minute. Following the thermal cycling, circuit measurements were then performed at the test temperatures of +25, -190, and +200°C.

Temperature Effects

The gain of the amplifier circuit at various test temperatures is shown in Figure 1 over the frequency range of 1 kHz to 5 MHz. It can be seen that the gain of the amplifier remained relatively the same, regardless of the test temperature, until the test frequency of about 200 kHz was reached. Beyond that frequency, the gain exhibited changes in its magnitude and roll-off frequency. For example, while the roll-off frequency (-3 dB) was at 800 kHz at room temperature, it increased to about 1.1 MHz at the high temperatures between +100 °C and +200 °C. Conversely, when exposed to cryogenic temperatures, i.e. -100 °C to -190 °C, the roll-off frequency of the gain fell in the range between 400 and 500 kHz. Although the circuit was tested at ten different test temperatures between -190 °C and +200 °C, only data obtained for five temperatures are reported as the omitted data (0, -50, -150, +50, and +150 °C) followed the same trend depicted in Figure 1. In terms of temperature, therefore, the amplifier circuit operated well in the temperature range between -190 °C and +200 °C; however, bandwidth did show a decrease with decreasing temperatures.

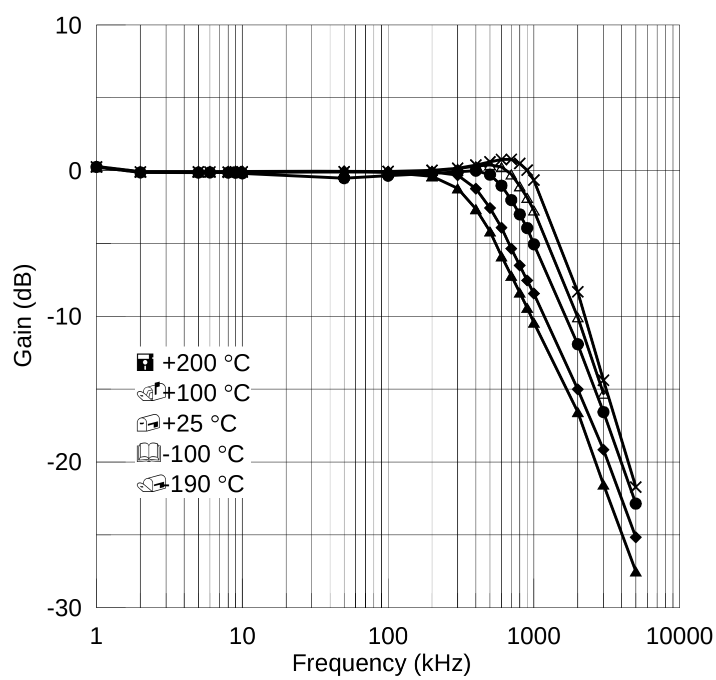

Figure 1. Gain versus frequency at various temperatures prior to thermal cycling.

Figure 2 depicts the phase shift of the amplifier as a function of temperature and frequency. Similar to the gain characteristics, at 200 kHz the phase began to change, most notably at the cryogenic test temperatures.

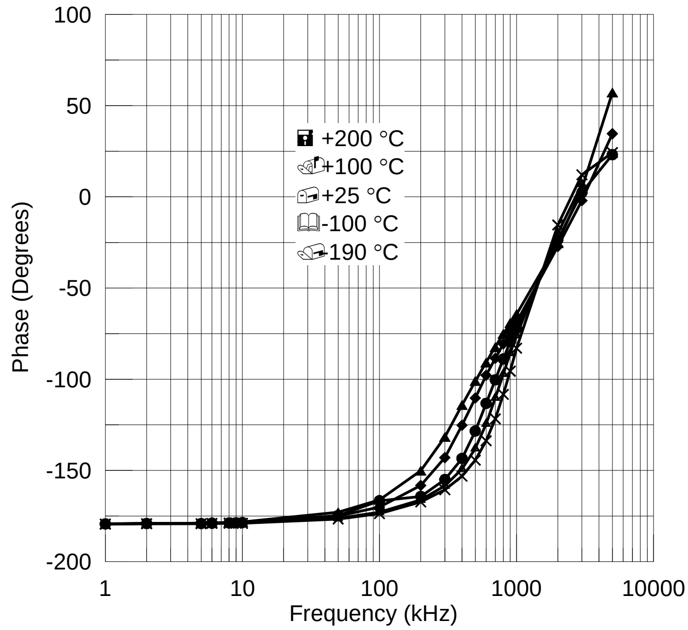

Figure 2. Phase shift versus frequency at various temperatures prior to thermal cycling.

The supply current of the circuit exhibited modest change with temperature as depicted in Figure 3. This change is reflected by a slight increase when test temperature was changed from room to either extreme, i.e. cold or hot. The increase in current at high temperature is attributed to maintaining a low drift in the gain-bandwidth product [2]. Although very thermally stable resistors were used, the circuit drew somewhat higher current at cryogenic temperatures.

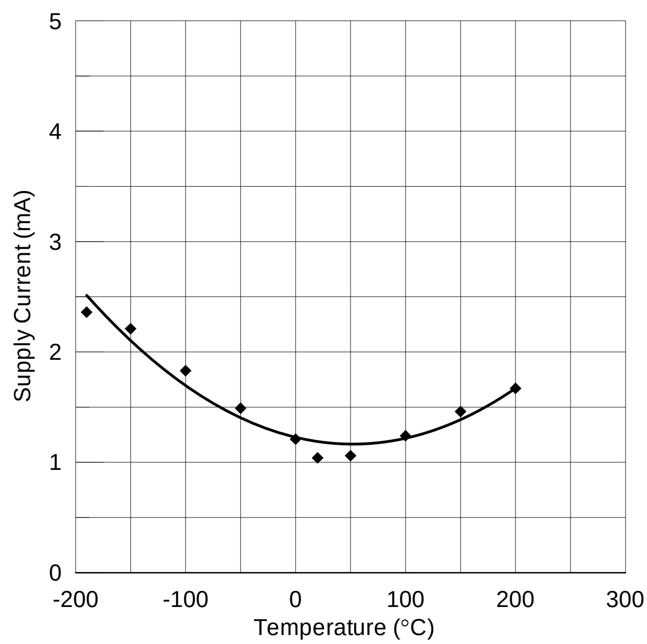

Figure 3. Circuit supply current as a function of temperature.

Re-start Operation at Extreme Temperatures

Re-start capability of the CHT-OPA amplifier was investigated at both -190 °C and at +200 °C by allowing the circuit to soak at each of these temperatures for at least 20 minutes without the application of supply voltage or input signal. Power was then applied, and measurements were taken on the output characteristics. The amplifier circuit was able to successfully re-restart at either of the two extreme temperatures, and the results obtained were similar to those obtained earlier at the respective temperatures.

Effects of Thermal Cycling

The effects of thermal cycling under a wide temperature range on the operation of the CHT-OPA operational amplifier were investigated by subjecting it to a total of 10 cycles between -190 °C and +200 °C at a temperature change rate of 10 °C/minute. The amplifier gain obtained after the thermal cycling is shown in Figure 4 as a function of frequency at the selected test temperatures of +25, +200, and -190 °C. It can be seen that these results were very similar to those obtained prior to cycling that are depicted in Figure 1 and, thus, it can be concluded that the thermal cycling had no effect on the amplifier's gain. Similarly, the phase shift of the amplifier did not undergo much change with cycling, as shown in Figure 5. In addition to maintaining its electrical performance with cycling, the operational amplifier chip did not suffer any deterioration or damage in its packaging due to this limited thermal cycling.

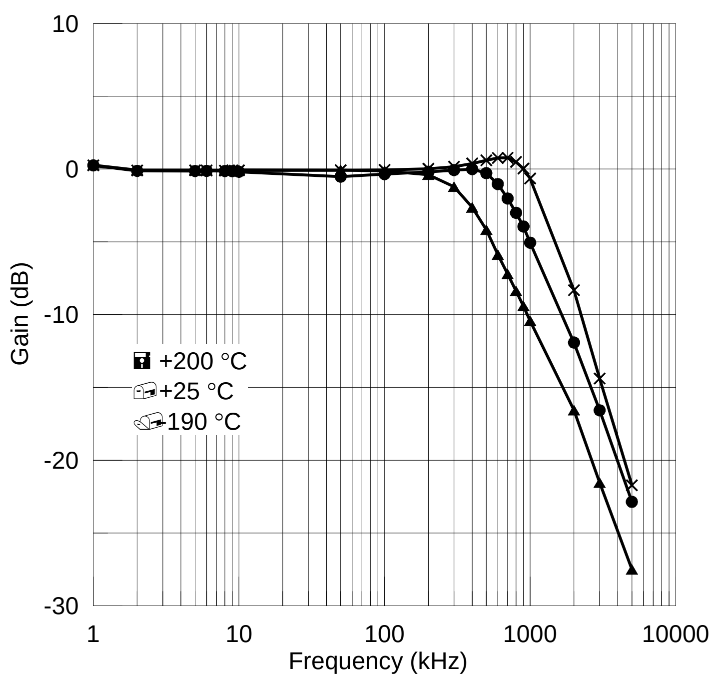

Figure 4. Gain versus frequency at various temperatures after thermal cycling.

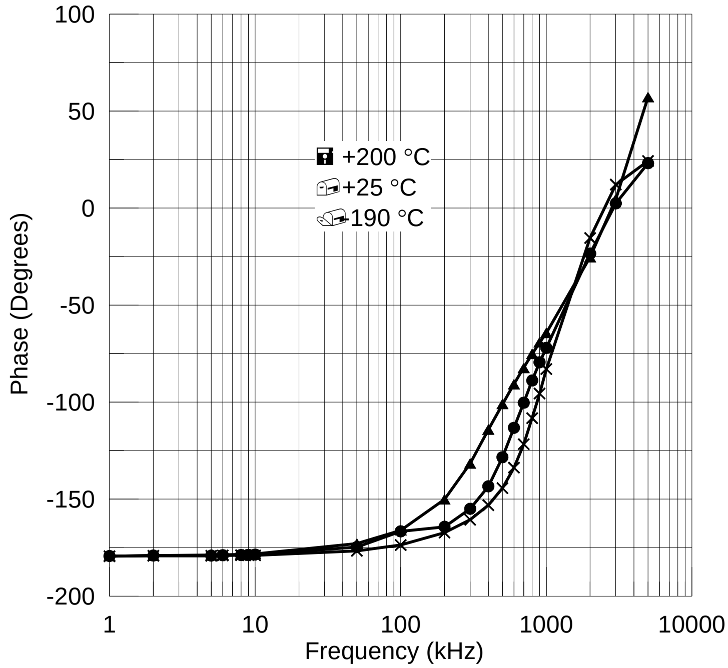

Figure 5. Phase shift versus frequency at various temperatures after thermal cycling.

The amplifier supply current was also recorded at various test frequencies and temperatures after thermal cycling. A comparison of these values obtained at the test temperatures of +25, +200, and -190 °C for pre- and post-cycling conditions are shown in Table II. The data reported are those obtained at 500 kHz frequency. Again, no major changes occurred in the supply current, at any given temperature, as a result of the thermal cycling.

Table II. Supply current at various temperatures for pre- and post-cycling conditions.

	Supply Current (mA)	
Temperature (°C)	**Pre-cycling**	**Post-cycling**
+200	1.67	1.68
+25	1.04	1.18
-190	2.36	2.94

Waveforms of the input (blue curves) and the output (red curves) signals of the amplifier were captured at 25, -190, and +200 °C prior to and after the thermal cycling. These waveforms are depicted in Figures 6, 7, and 8 at the test frequency of 100 kHz, 500 kHz, and 1 MHz, respectively. The data in these figures again illustrates that the amplifier did not undergo any changes in gain, phase, or waveform after subjecting it to the ten thermal cycles. Thus, it can be concluded that this limited thermal cycling activity performed on the circuit had no influence on its operational characteristics.

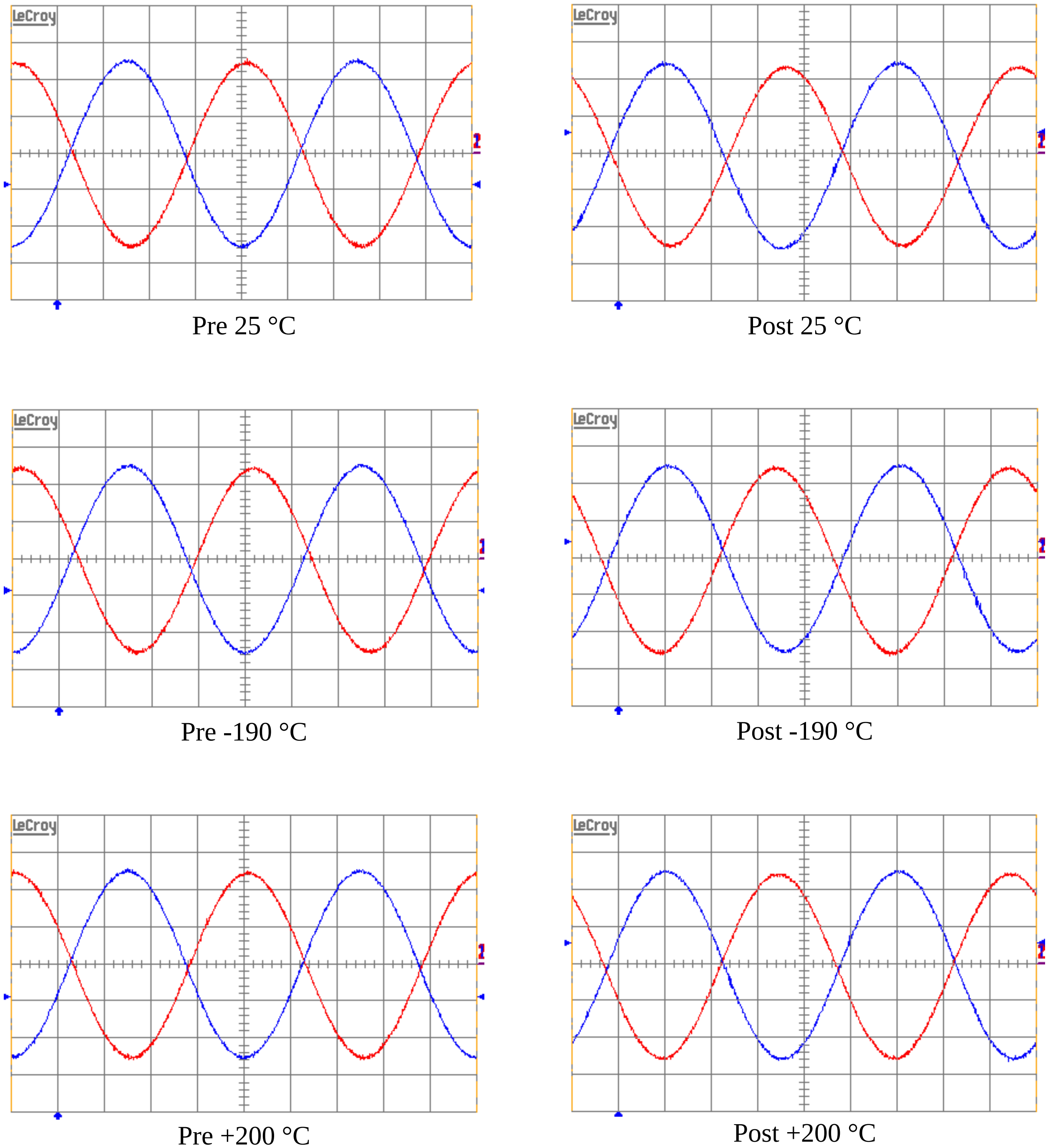

Fig 6. Input (blue) & output (red) waveforms at various temperatures at 100 kHz for pre- and post-cycling conditions. (Scale - Vertical: 200mV/div; Horizontal: 2μs/div)

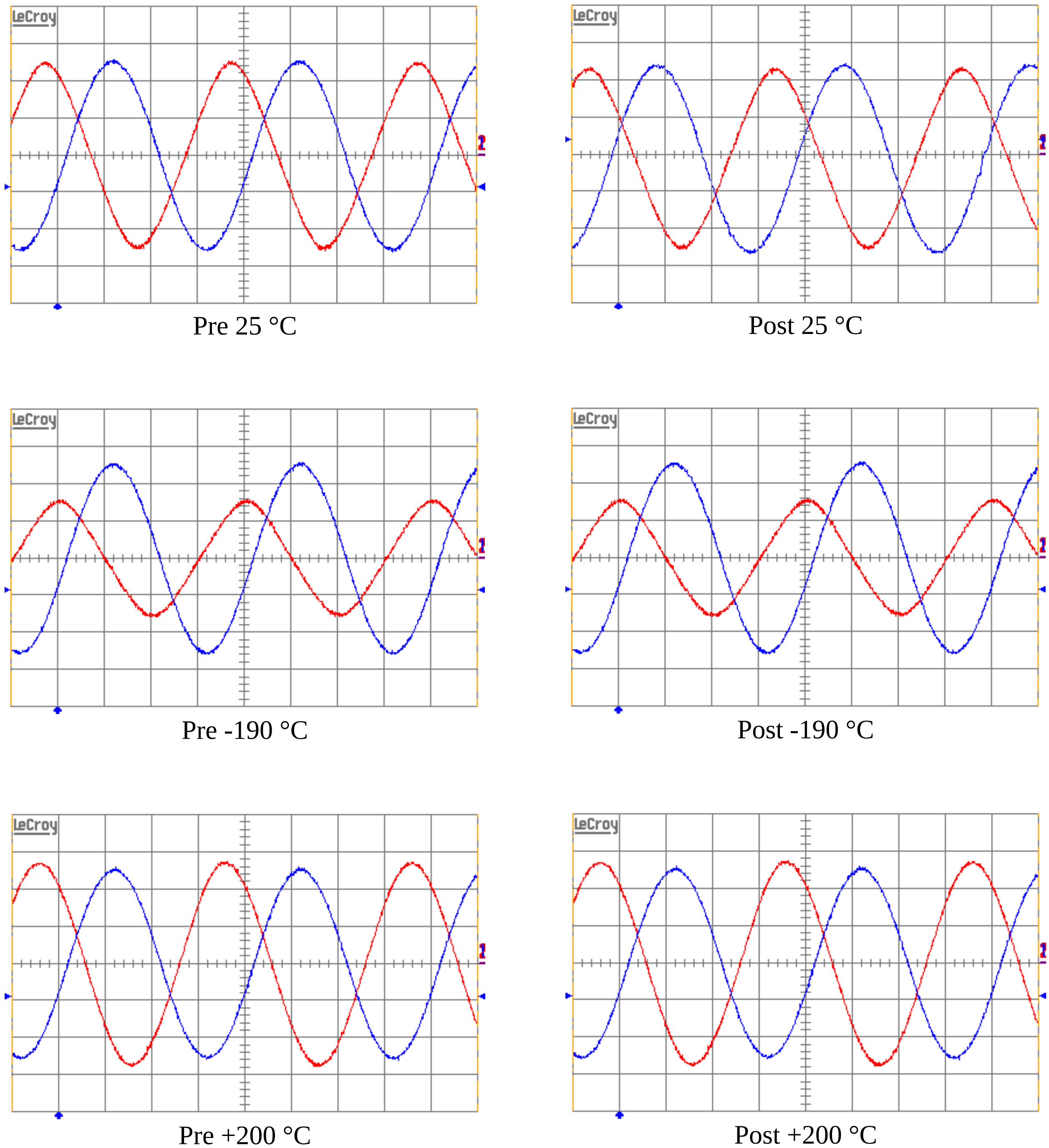

Fig 7. Input (blue) & output (red) waveforms at various temperatures at 500 kHz for pre- and post-cycling conditions. (Scale - Vertical: 200mV/div; Horizontal: 0.5μs/div).

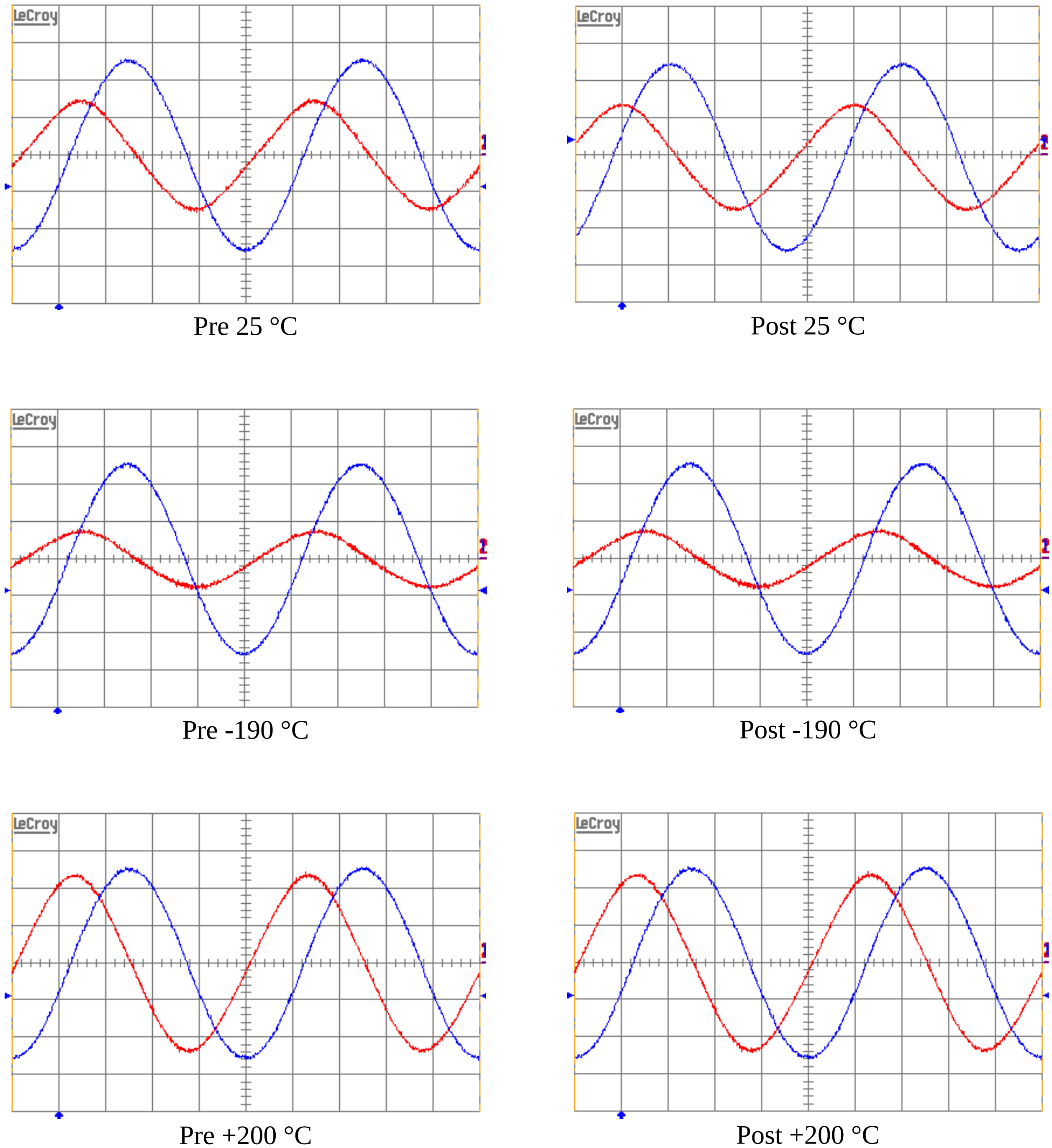

Fig 8. Input (blue) & output (red) waveforms at various temperatures at 1 MHz for pre- and post-cycling conditions. (Scale - Vertical: 200mV/div; Horizontal: 0.2µs/div).

Conclusions

A new operational amplifier chip based on silicon-on-insulator technology was evaluated for potential use in extreme temperature environments. The CHT-OPA device is a low power, precision operational amplifier with rail-to-rail output swing capability, and it is rated for operation between -55 °C and +225 °C. A unity gain inverting circuit was constructed utilizing the CHT-OPA chip and a few passive components. The circuit was evaluated in the temperature range from -190 °C to +200 °C in terms of signal gain and phase shift, and supply current. The investigations were carried out to determine suitability of this device for use in space exploration missions and aeronautic applications under wide temperature incursion. Re-restart capability at extreme temperatures, i.e. power switched on while the device was soaked at extreme temperatures, was also investigated. In addition, the effects of thermal cycling under a wide temperature range on the operation of this high performance amplifier were determined. The results from this work indicate that this silicon-on-insulator amplifier chip maintained very good operation between +200 °C and -190 °C. The limited thermal cycling had no effect on the performance of the amplifier, and it was able to re-start at both -190 °C and +200 °C. In addition, no physical degradation or packaging damage was introduced due to either extreme temperature exposure or thermal cycling. The good performance demonstrated by this silicon-on-insulator operational amplifier renders it a potential candidate for use in space exploration missions or other environments under extreme temperatures. Additional and more comprehensive characterization is, however, required to establish the reliability and suitability of such devices for long term use in extreme temperature applications.

References

1. CISSOID Company “CHT-OPA: Release of Preliminary Usage Information,” Data Sheet, Doc. RP-070053, V01.01, July 2007.

2. Gonzalo Picun et. al, “A High Temperature General Purpose Operational Amplifier with 300 µA Bias Current and 4.5V to 20V Supply Voltage in Partially Depleted CMOS SOI.” International Conference on High Temperature Electronics (HiTEN 07), Oxford, England, September 17-19, 2007.

Acknowledgments

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